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A Novel Hybrid Approach Leveraging Shehu Transformation, Akbari-Ganji's Method, and Padé Approximant for the Resolution of Diffusive Prey-Predator Systems

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ABSTRACT

This study introduces a novel method aimed at deriving approximate solutions for diffusive prey-predator systems. The proposed method seeks to circumvent the limitations of extant techniques, which frequently grapple with obtaining accurate analytical solutions and managing intricate computational operations. This new approach amalgamates the Shehu transformation, Akbari-Ganji's method, and Padé Approximant to facilitate a more precise and efficient solution. The accuracy, efficiency, and effectiveness of the proposed method are assessed through the analysis of two exemplar cases in one- and two-dimensional spaces. Results gleaned from the novel method underscore its superior accuracy and efficiency compared to traditional methods used for approximating analytical solutions to similar problems. Further, the utilization of infographics and tables elucidates the significance, validity, and indispensability of the proposed approach. This research augments our comprehension of biological systems and their interactions with the environment, thereby presenting a valuable contribution to the academic discourse.

1. INTRODUCTION

Predator-prey dynamics form the cornerstone of vibrant ecosystems, with the relationship between predator and prey constituting a pivotal interaction among the various interspecies partnerships in ecology. Differential equation-based mathematical models are typically employed to simulate interactions where populations overlap. The seminal predator-prey model was introduced by Lotka and Volterra in the early 20th century, consisting of two first-order ordinary differential equations [1, 2]. Subsequent academic discourse has yielded numerous models addressing diverse problems related to intricate natural interactions. Notably, valuable contributions have been made by researchers employing density-dependent reactions [3].

The stability of fixed points is a critical issue in population dynamical models, with numerous mathematical models presented to explore this [4-8]. Furthermore, the resolution of the predator-prey relationship is another targeted area, as evidenced by several studies [9-12].

Reaction-diffusion systems have been scrutinized across various disciplines, including physics, chemistry, biology, and economics [13-19]. Particularly, it has been established that these systems can generate self-organized patterns. The system dynamics, specifically the fusion of nonlinear reactions of growth processes and diffusion, are solely responsible for these spatial patterns, not the inhomogeneity of initial or boundary conditions [20]. Turing instabilities are chiefly accountable for stable spatial pattern developments, with the co-development of Turing and Hopf instabilities inducing steady spatial structures and temporal oscillations respectively.

Despite the evident importance of studying this system via various simulation techniques, the nonlinearity of these equations poses a challenge to their resolution using integrative transformation methods. Existing knowledge indicates that combining integrative transformations with analytical methods can reduce computational operations and complexity [21-23].

Among the many analytical methods for solving differential equations is the Akbari-Ganji approach, developed by Mirgolbabaee et al. [24], applicable to a range of nonlinear ordinary and partial differential equations. Meanwhile, the Padé approximation, crafted by Henri Padé in 1890, optimizes the accuracy and convergence of solutions by approximating a function near a specific point [25]. More recent is the Shehu transformation, introduced by Maitama and Zhao in 2019 [26].

Present challenges in prey-predator models include difficulties in obtaining accurate analytical solutions and managing complex, time-consuming computational treatments. To mitigate these issues and to procure more precise solutions expediently, this study proposes a new method: the integration of the Shehu transformation, the Akbari-Ganji method, and the algorithms of the Padé approximation method, henceforth referred to as SAGPM.

This paper is divided into seven sections. Following this introduction, Section 2 presents the proposed technical algorithm, which is then applied to analyze various diffusive prey-predator systems in Section 3. Subsequent numerical results are introduced and compared with earlier works in